Mind Molding

**Melanie Challenger**I’m going to be speaking with Nirosha Murugan, Assistant Professor in the Department of Health Sciences, Wilfrid Laurier University in Canada. Nirosha’s lab adopts a top-down approach to understanding the biophysical language of cellular communication, which can be used to gain insights into disease pathways and breakthroughs, and also, as we’ll be finding out, the intelligence of curious organisms like slime moulds

**Melanie Challenger**

So we're going to be talking about slime moulds. And for many of our audience, I think they probably won't even know necessarily what a slime mould is, or how to categorise that kind of animal. If we think about it as an animal, or where we might come across this kind of organism, can you start before we go any further into your research by getting our audience up to speed with all of that?

**Nirosha Murugan**

Absolutely. So slime mould, or the particular strain that I work with *Physarum polycephalum* is actually quite common in our everyday environment if you live next to a forest, so they commonly grow on sort of humid environments, sort of on forest floors behind, or underneath leaves with tree barks. And the classification of slime mould is actually quite interesting because you know, it is let's say mould in the name, but they're not a fungus at all, they actually fall into the category of a protist. So the structure in the anatomy of the slime mould, it has spores, and it grows into this big network of what some people call the yellow blob. And this the actual structure of the Physarum is quite interesting if we actually delve deeper into the anatomy of it.

**Melanie Challenger**

So I think we still probably want even more. I was teasing a bit with how we think about these creatures, right? These organisms, I should say, I think the thing with slime moulds is, it's very difficult for people to understand exactly what they are. And even if you find one. So I lived in the middle of a 9000 acre forest. And I remember with my kids, we were just walking through some clear fell. And it's a very damp forest in England, and there was a piece of clear fell, and on top of this was this kind of whitey yellow. I don't even know how to describe it, strangeness. But it was unquestionably a slime mould when we went back and tried to identify it. But obviously, in this forest, we see fungi of all kinds of strange forms along with various animals around us. So how can we understand what this organism is and where it came from? Where it sits within the evolutionary tree?

**Nirosha Murugan**

Yeah, so scientists have actually kind of done this taxonomic classification, by understanding its lifecycle, how it behaves, how it grows from its fruiting body state to its full form. So there's many different species, as I was saying, of Physarum, you do see that yellow fluffy type, or sometimes, as you mentioned, the white fluffy type. And fun fact, actually, like if it looks yellow and fluffy and kind of oozy. It's actually called the dog vomit strain or type.

**Melanie Challenger**

I think that was what we saw, we saw the dog vomit, that was what delighted us when we looked it up later on the internet. I found dog vomit, what the hell is it?

**Nirosha Murugan**

Correct, it's quite a fascinating thing to see. And it depends on how it grows. And if the biological classifications of the actual Physarum itself. So yeah, so they create the slime nets, once they're in their adult stage, when they're actually foraging on the forest floor for nutrients. And typically in their nutrients is lower the environment is not as conducive for survival, they will kind of shrivel back down into their sort of hibernating state. And that's kind of what we know about the slime mould itself. It's not a new model system. People have looked at it and studied it quite heavily in the past, but it's new in the sense of how we use it in the context of cognitive biology and cognitive science.

**Melanie Challenger**

Right, so are we looking at an it or a they? Before we move on to the ways that we're starting to, you know, the ways that this organism has become of interest now in cognitive science?

**Nirosha Murugan**

I mean, that's an interesting question. When you look at the Physarum as a unit, it is actually one cell. If you go on to the forest floor and you do see a pile of dog vomit. It is actually one cell that has this undivided membrane. So when a cell divides, we know that it pinches off in cytokinesis, and you get two separate membrane cells. But Physarum doesn't undergo that process and it keeps those membranes connected. So we could call it a they and it can be that it depends on the stage and the context that you're looking at it.

**Melanie Challenger**

So tell us how the history of how Physarum became of interest in cognitive science, what was the kind of starting point for that? And how did you become interested in this strange kind of phenomena?

**Nirosha Murugan**

Yeah, so to answer your first question, I think, you know, looking back in the literature, just understanding it from a biological and taxonomic point of view, understanding that this is actually not a fungus, and it classifies under the protus or amoeba category. And a lot of researchers use the amoeba state where it's a sort of single cell that you can culture in a flask. And they use it for understanding, you know, just comparing it to bacterial cultures, trying to transfect it and trying to grow certain drugs and things like that. But when you look at the entire Physarum, or the slime mould itself, it's plasmodial state. And that's what we look at it is when it's in its big network state. I think that the first research started with when individuals are trying to understand its ability to solve mazes. And there was a Nature paper that was first published on that where it showed that this organism could traverse and quote, unquote, ‘solve’ a maze. So I think that was one of the first big breakthroughs in this area.

**Melanie Challenger**

This is how I came to all of this research too. And, you know, I think at the moment when we're trying to do comparative cognitive work, so for instance, you know, there's a lot of research being done at the moment in trying to get bees to solve mazes. And we, we create these different conditions on which we think we can look for intelligent behaviours. And in particular, we can perhaps glimpse the hints of what we call thinking now all the time, our definitions get problematic, don't they? And we have to just work with an acceptable, flawed definition in order to move forward in a conversation or even just to sort of build our hypotheses in. But we can, most people listening can totally get their heads around the idea of what a honeybee might be doing. They understand, you know, even though it's still a big leap, isn't it? It's still maybe only since the 1970s, that people have started to think that insect cognition is of interest and much more complex and intelligent than we thought. But it's still, even though it's not a mammal that we're doing comparative cognitive work with it, it still feels accessible for us in terms of understanding, but when we're talking about, you know, we make jokes - don't worry about amoebas being the kind of simplest and brainless. So what are we looking at? I think it's just so, beyond many people to think that an organism, a very simple organism could do something like solve a maze. So what is it that this research does practically and what has been shown and then we can sort of dive a little bit more into to what this might say about how we think about intelligence and minds?

**Nirosha Murugan**

I think generally, when we're taught and you hit it at the beginning, in we're talking about, you know, defining cognition and decision making, and you know, looking at these, not, I would say, as typical systems when we're studying cognitive biology, like a bee, a fruit fly and things like that. I think we're trying to get down to the idea of when an organism is met with or it gets forced to make a decision. And I think that's why the mazes are these great tools. Because you know, when you're in a lane, you're going left or right, you have to make a decision because you have to think about the energy utilisation. You can't traverse forever. You know, that's not energetically favourable. So, in the case of the Physarum, as I was saying, it's a single mass, so it doesn't move as freely as a bee or a flight, so it has to, to anthropomorphize the system, it has to utilise its energy network and more efficiently and strategically than to grow in all sorts of avenues and explore the avenues. And I think that's where we hit it in our experiments where we show that the Physarum doesn't actually need to explore its environment to figure out where there might be a food source or not. It can actually make these decisions ahead of time by picking up cues in its environment.

**Melanie Challenger**

So what happens in this maze, you set up a problem in its environment that the Physarum has to solve? How are they going about solving this? And what have they been the more sort of astonishing things that have come out of your research?

**Nirosha Murugan**

Yeah, so just kind of touching upon previous research that's been done by some of these biophysicists’. They've used chemical cues. So some sort of chemo attractant to kind of guide the Physarum in certain ways. And these mazes, they typically have some sort of nutrient source, whether it be a sugar or oats is funny enough what Physarum loves to eat.

**Melanie Challenger**

Me too.

**Nirosha Murugan** 11:22

And so in the maze, they're actually kind of being guided, I would say, by some sort of nutrient source and what's different in our study, and I think it kind of pushes the envelope a little bit further about decision makings. And we have no chemical attractant or nutrient in our decision making arenas, and they're actually inert glass discs. So that kind of begs the question, what is Physarum sensing, how or what information is picking up in its environment to make these decisions? And that is like the fundamental basis of our research question.

**Melanie Challenger**

So what cognitive, we get kind of a more complex multicellular organism is utilising lots of different systems, we’re very brain focused, aren't we when it comes to cognition, but we do know what we're becoming. We're sort of subtlizing that research, as time goes by and recognizing all of the resources that an organism uses to make good decisions and to make the best decision and to remember, a good decision in the future, or to act, when, you know, a previously used good decision is no longer going to work well in the environment. So we can kind of get a sense of all of the sorts of biological resources that we use from nervous systems. Your brain and neurons and so forth. What is the Physarum using to make these sorts of decisions in the environment?

**Nirosha Murugan**

That is the question isn't it? Obviously something that we tried to explore in our experiments. And as we kind of touched upon earlier, Physarum, as a model system is relatively new. So we don't know a lot about it, we don't know the nitty gritty details about the molecular mechanisms of how an exploited environment and learns and remembers, I mean, it doesn't have a neuron. So we can't really do our traditional patch clamping techniques to look at its electrical signature. But what we have done is kind of taken a different approach and used sort of biophysical techniques to understand how it's reading its environment. And so we created an arena that is just the only variable that is changing is mass, and how that mass is distributed. So from our experiments, we hypothesise, you kind of have strong evidence to suggest that the Physarum is actually able to pick up mechanical cues. And we now know that they have these mechanical receptive scent or mechanical sensitive channels, I should say, on their membranes, that respond to changes in their environment that again, gets translated inside from a biological point of view.

**Melanie Challenger**

What's Physarum from an evolutionary perspective, what are they trying to achieve in their environment?

**Nirosha Murugan**

I think, you know, trying to read the mind of a Physarum is quite interesting.

**Melanie Challenger**

I think, especially in the absence of a mind.

**Nirosha Murugan**

Correct. If you boil it down to and you've watched, you know, 1000s of hours of Physarum moving ever so slowly in these experiments, I think it has to do something with survivability and its environment, right. You know, if you talk about evolution and its adaptability to survive, it has to do with finding some sort of nutrients. So I think it has to do with Physarum is exploring environments for nutrients and how it grows on the forest floor, looking for decaying materials, that's a nutrient source for the Physarum. So it has to constantly explore that area or environment to survive.

**Melanie Challenger**

See, what I find thrilling about this research is what it has to say about other areas of research, of course, I mean, it's fascinating in and of itself. But it feels to me like we are looking at or potentially looking at one kind. Or it doesn't have to be the origin story of intelligence, but it seems like we're looking at it kind of early kind of proto intelligence. So what sorts of questions are coming from this research in terms of life origins? How you kind of get chemistry shifting over into biology? Do you do see this as potentially helping, you know, being a part of that puzzle that we're just sort of trying to put together at the moment?

**Nirosha Murugan**

Absolutely. I think just studying slime moulds, I’d say atypical systems, it kind of helps us redefine what we think intelligence really is. We've been studying the brain for quite a long time. And I think we're competent to saying we've made significant strides in the field of neurobiology. But I think, there's still a lot of unanswered questions. And I think by studying aneural systems, or atypical systems, like the slime mould, it gets down to the fundamental question of how we're processing our information. And isn't that what intelligence is? How we bring in information, process it and adapt to it in the future, when that same information is presented, maybe in the same way, or an alternative way. And I think, looking at various organisms across, you know, different taxonomic groups, it gives us a really holistic picture of what intelligence is, and I think there's a lot of good research that's being done right now to even look at swarm intelligence. When we have one organism that's part of a unit that is, quote, unquote, ‘Intelligent’. And, I think you know, looking at a typical system, it'll give us I think, it also gives us insight to what we should be exploring in neural systems and, and in computational biology, I think this is a field that I'd say, blending together, you know, artificial intelligence, cognitive biology, and computational neuroscience, I think they blend very nicely together. And I think looking at systems like *Physarum polycephalum* is a good start to do that.

**Melanie Challenger** 18:08

I suppose the fascination, certainly for me is trying, you know as you say, one of the other things that this kind of work does is complicate the philosophy and it complicates the definitions. So, you know, if we allow what we're talking about in intelligence to get too wide, which might not necessarily be a bad thing, but it does affect sort of necessarily what we might be talking about in terms of the story of life on Earth. I can see how you look at water for instance, and fluid dynamics work you can see efficiency everywhere in physics, right? So what is fascinating for me is that this research seems to sit in a kind of liminal place where those sorts of things which are fascinating and efficient and logical but t are not what we're defining as intelligent life or we don't even have to put intelligence in there, but not what we're defining as life, as a system that has come to life. Slime moulds and the way, what we're starting to get a hint of might be helping us to answer those questions about how we define life itself, let alone intelligence, because perhaps intelligence which of course, I know you work with Mike Levin. And you know, he's doing a lot of work on agency and sort of cognition all the way down. Are we seeing here an origin story, not only for life, but the fact that intelligence is, as we understand it, is kind of baked in right from the beginning at that transition?

**Nirosha Murugan**

I think so. That's an interesting point that you bring up of all systems following the laws of thermodynamics and being efficient. But what is efficiency from a biological point of view? And if you look at organisms from the origin story and beginning of time, how they adapt to their environment and propagate, is, I guess, rooted in their efficiency to survive? And is that intelligence? Is that a concept that gets propagated through time? I think that's something that using systems like, say, slime moulds, and aneural systems or even plants, I think they give us some hints, hints into how information, (I think it boils down to information), how is it that we are passing this information on from one system to the other, or even from one generation to the other?

**Melanie Challenger**

How does this work tie in with AI, then? You mentioned AI a little earlier, and this sort of cross pollination going on? What does it have to say, for that field of research?

**Nirosha Murugan**

When we're thinking about artificial intelligence, we're thinking of smart beings. And, you know, we have smart TVs, and smart lights, and all these things, and they're all artificially controlled, and they're artificially intelligent, but they're essentially all processing information and predicting the best network, that is, again, we're coming back to that word that is most efficient, and Physarum, (and there's lots of research that's independent from what we've done, where they've actually shown the efficiency of Physarum) that can recreate you know, modern industrial rail networks. So the body plan and the morphogenesis of how the Physarum can grow is efficient, by definition in terms of how they make their body plan or their network. So who's on how the Physarum is able to sort of do this and create these efficient networks is something that I think AI has an in the field of AI is borrowing from, to make these, you know, future decisions based on past behaviour.

**Melanie Challenger**

Let's go back a little bit to what this has to say, of our definition of intelligence and how we value that intelligence. So I think for me, you know, I work a lot in in bioethics and we're always concerned, to, with really very mammalian ways of being intelligent most of the time, and oftentimes very human ways of being intelligent. But our perceptions of intelligence are very value heavy, we sort of cling to, you know, smartness, we talk about smartness and smartness has a positive value assumption within it all the time. And sometimes, though, with human beings, it's the kind of chaos of our intelligence the way in which actually systems once they start responding and decision making, get, you know, a kind of chaos creeps into it. And, and it's out of that chaos that we get a greater kind of movement towards complexity. So in these very, very simple systems, where we're seeing an intelligence that seems very sort of basic and very pattern based and still sort of very tied to, as we were saying, pure efficiency. Are you seeing any chaos in there at all? Or any learning? Dare I say it that that might be creeping in?

**Nirosha Murugan**

I think, absolutely. And I think that's something that we didn't expect when we did the study and it was very eye opening. For me anyways, when we did this experiment, just to kind of give our listeners an overview. We had a Petri dish with the Physarum in the middle and a decision on either side equidistant from each other. And the Physarum was, you know, allowed to grow in whatever direction it pleases. And what we saw when we actually watched the Physarum over the 24-hour growth period, you see that for the first 10 to 15 hours, it quote unquote ‘buffers’, like a, you know, a webpage buffering the growth equally in either side, sort of as if it's thinking about what is the next growth pattern should be. After that, and it's pretty unreliable. Within that 10 to 15-hour period, it makes a decision, whether it grows towards a higher mass, or a mass that is highly distributed over the space. So this thinking, and I think Physarum is thinking, what it’s thinking, processing the information that is in its environment, and what we're thinking is processing the changes in the physical features associated with the agar that it's placed on. And that's our interpretation of the thinking of the Physarum.

**Melanie Challenger**

I mean, I, I'm pausing just because it kind of it does blow my mind, because we haven't got a mind here have we? So what is doing the thinking? And how much can we reduce this thinking down to a kind of really what all cells are in the business of doing?

**Nirosha Murugan**

And you know that's what got me interested in this work. Having been trained in the field of neuroscience, I've been kind of moulded into this thinking pattern we're using this thinking you know, information comes in through a neuron, it goes through this thing that we call the brain, something process it and it goes out through a motor output through our arms or legs or some sort of motor system. And when I was doing this research, I tried to put that principle into the Physarum. What's coming in, what's processing it and what's going out. And studying and knowing the biology of the Physarum and knowing that it doesn't have a neuron? Where is that information? How is it coming in? Okay, so in our research, we see that, okay these mechanical sensitive ion channels, that's what's bringing in the information. All right, that's interesting. No, but where's the processing happening? There's no brain? Is it happening throughout the entire body plan of the Physarum, but then how is that information getting from one side to the other? Because Physarum can grow from a centimetre all the way up to a meter? How is that information getting there so fast? And all of these questions are things that you know, we're trying to answer. And, and that'll give us information about maybe information processing in this very rudimentary input processing output is one approach to intelligence and thinking. And there could be other ways that we could be doing the same thing.

**Melanie Challenger**

What does competition look like in the environment with slime moulds?

**Nirosha Murugan**

Ah, there's some really cool research that's been done by Dr. Dussutour out in Toulouse, France, which I had an opportunity to work with. And she did this exact experiment where she had two different strains of Physarum. One from Carolina, the United States, and one from Australia, and she put them in a dish, and, you know, allowed them to grow. And surely enough, just like in any other biological population, one outcompetes the other. What that usually means is that one takes over the environment, and the other strain that isn't as successful will sort of die back in a sense, it'll stop growing. And if it stops growing, it just leaves behind an actual slime trail, and that Physarum ceased tp exist. So my goodness, yeah, and it's actually super cool. If you look at a dish, you can actually see the memory of the Physarum, or I should say, the past behaviour of the Physarum because it leaves behind a slime trail. So you know, where it was and what it was thinking.

**Melanie Challenger**

So it has a give up mechanism, if there's no point in,

**Nirosha Murugan**

Absolutely

**Melanie Challenger**

Out competed in its environment

**Nirosha Murugan** 29:14

Yes. And if it doesn't even have, it could, you know also kind of compete with itself. For example, if you have a Physarum and as I was saying, it grows in a very large space. If one side of the Physarum is not getting enough nutrients or information, it'll actually die back and it'll propagate towards, you know, the other side. So, as a whole body it sort of competes with itself of, you know, should I grow towards this left area versus right and so forth?

**Melanie Challenger**

Completely fascinating. What are you going to do with this research in terms of comparative cognition across other taxa and where are you going next with all of this?

**Nirosha Murugan**

So this work is done in collaboration with Dr. Levin and Dr. Ingber at Tufts and Harvard. And I think one of the things that we want to explore a little bit more is the where is this happening? And you remember that thinking period and buffering period? What is the Physarum actually doing in that period? I think that's super fascinating. Yes, we've shown that it can grow and make these decisions based on mass. That's our first step. But what's happening in that buffering period from a molecular point of view? And could that give us some insight, could we even extrapolate that even to a neural system and compare that approach?

**Melanie Challenger**

Kind of like a state of mind? Very interesting. What kind of experimental models and procedures are going to use to try and access answers to some of this?

**Nirosha Murugan**

So when I was working with Dr. Levin, we tried to use some of the traditional neuroscience approaches reading the electrical states of Physarum. And that's something that I think could we be exploring more is that we created these multi electrode arrays, that the Physarum grows on top of, that we could actually record the electrical impulses coming from the Physarum as it's growing over the electrodes. So that's one approach. And as we know more and more about the genetics and the genome of the Physarum, we can start doing some of the fancier work where we can actually put in some of these actuators and readouts to look at the bioelectric states of the Physarum as it's going through these cognitive tasks to see how it's membrane physiology changes as it's learning.

**Melanie Challenger**

I'm curious to finish off as to how you ended up getting into all of this in the first place.

**Nirosha Murugan**

So my academic training and everything that I'm interested in has to do with how information gets processed. I started off applying neuroscience principles to understanding how cancer even transforms from a healthy state. What is it in what is in our body that changes a healthy cell to a cancer cell? And when I came to Mike Levin's lab, we both share the same interest of how information gets processed. And he has worked in regenerative biology and you know, regrowing limbs. And that's one aspect that I was working on. And the other aspect is, let's use a system that doesn't have any neural components to see how it processes information. And that's where it all began.

**Melanie Challenger**

 And what about when you were just a little girl though? Did you see that you were going to end up working with these crazy organisms?

**Nirosha Murugan**

I can confidently say no. I grew up in a really, really busy city. So there wasn't really many opportunities for me to come across slime mould. But I'm thankful that I did. I transplanted myself from a big city to a smaller city in northern Ontario, where there's lots of trees and forests. And it's an appreciation that you don't get to have until you're actually in it. And then you start to apply these principles that you learn in the lab and class and wherever, to ask these important questions. And that's kind of I would say, what got me interested in information processing throughout all biological systems.

**Melanie Challenger**

I bet you can't look at a subway map in the same way.

**Nirosha Murugan**

Oh, no, absolutely not. I feel like Physarum’s changed me just as much as I can change it. Anytime I see a network, I go, Oh, that looks like a neural network or a vasculature network or a train network. They all have these parallels with each other and in other than the fact that the slime moulds growth on a dish is beautiful, there's so much information that we can learn from it. And there's not enough time in the world for me to do that right now.

**Melanie Challenger**

I think that's always the sign of good research, isn't it, where it transforms just even a walk through a city for the individual. So, it's lovely to talk to you and absolutely fascinating and when, when you get to the next stage of the research, maybe we can get you back on to talk about that.

**Nirosha Murugan**

Absolutely. Thanks again, Melanie for letting me share my work and my insights to this stuff.

**Melanie Challenger**My son has been drawing and designing transport systems since he was about four years old. There’s little that makes him happier than a beautifully mapped and efficient subway system. Recently, we were in Oslo, and my son was sat in the back of the car, spellbound, as we headed away from the city. After a while he said, Norwegians really design good road systems. This is not how my own brain works. But I admire his perspective, and his ability to sense what is otherwise completely invisible to me. Still, I teased him that the slime mould could probably outsmart him when it comes to rail networks. Yet, as is typical of the freedom of thought possessed by the young, he didn’t see this as an insult. In fact, he spent a good month or two trying to persuade me to allow him to house some slime mould at home so that he could study them himself. The kinds of research projects that Nirosha works on are head-spinning because they confront us with the staggering oddness of living systems. We are so wowed by multicellular beings like us that a cell can seem like a rather paltry affair. But anyone who has properly thought about cell division knows how elegant and extraordinary this process is. And the more we learn about intelligence at a cellular level, the more we have to be amazed by that a bunch of molecules, some several billions, united to become a being, however small, however humble, that can gather what it needs from its surroundings and stay alive against the tides of physical chaos